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Summary

This paper presents an overview of the sequencing of Nova operations leading up to propogation of the optical pulse. Control techniques include checklists, computer controlled sequencing, programmable logic timers and oscillator electronics. Ensuring personnel safety during laser operation is a safety interlock system which is designed to be both independent and compatible with the laser control system.

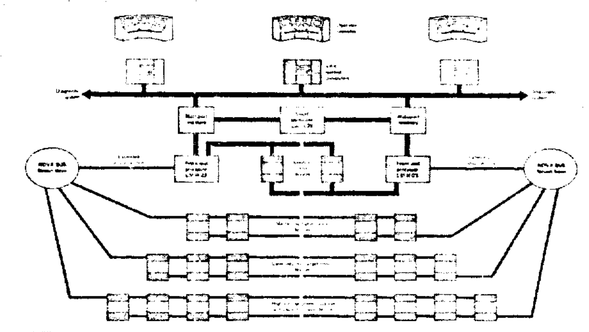
The steps required to operate the Nova laser occur in a predefined sequence and span a time of many minutes. Early activities relate to alignment of the laser chains and setup of laser/target diagnostic sub-systems. These steps are semi-automatic whereby computer programs assist operators in completing a checklist of setup operations. When all preliminary setup is accomplished, an automatic sequencer program then controls and monitors systems for the final minute. During this time period, the energy storage capacitor banks are charged. At ten milliseconds prior to switchout of the optical pulse, control of the laser systems is transferred from the computer to integrated logic timers. One of the timers activates the master oscillator fast timing system at switchout minus one microsecond. The oscillator electronics then generates a sequence of triggers accurate to one nanosecond.

Of primary importance during the operation of the laser is the safety of all personnel. Potential hazards include high voltage, high intensity laser beams and radiation from high energy target shots. The system of barriers, sensors, displays and controls specifically designed to prevent personnel hazards is called the Safety Interlock System.

Introduction

Nova is a powerful neodymium-doped glass laser facility intended to produce and characterize ICF micorexplosions. Controlling this laser is a sophisticated computer network interfaced with a variety of electrical, electro-mechnical and electro-optical devices; used to mechanize and automate alignment of optical components, perform diagnostic testing of laser/target performance and to provide real-time control of laser operations. This last function is performed by the Power Conditioning Control System. It synchronizes all active laser components (amplifiers, isolators, shutters) with the master oscillator/pulse-generator, monitors laser systems during the firing sequence and controls and monitors pulsed power segments of the laser system.

The control system architecture (Figure 1) is based on the use of multiple computers exchanging information via a shared memory and communicating with laser devices via an extended computer bus. The control system computer bus network is called NOVABUS and is implemented using fiber optic cables. The NOVABUS design features global synchronization bits and is connected with each device that requires synchronization or control during a shot sequence. Synchronization via NOVABUS is accurate to 1 μs; synchronization of devices requiring sub-microsecond timing is accomplished using triggers from the master oscillator electronics. This subsystem is hardwired and employs very broad bandwidth circuitry enabling electronic and optical pulse synchronization to less than 1 ns in critical applications.



Block Diagram of the Nova Power Conditioning Control System

Figure 1

Laser Sequencing and Synchronization

All mechanical, optical and electrical components of the Nova system must function in a coordinated manner. Failure of any component to perform its' design function results in degraded laser performance. Therefore, validation of all laser subsystems is accomplished prior to propogation of the laser pulse. Furthermore, failure of certain key components can damage the laser itself. For example, an early breakdown of the railgap portion of the plasma shutter could cause reflection of the full energy laser pulse back through the laser chain with consequent damage to several costly 46 cm aperture optical components.

Preparation of the laser involves system, subsystem and component verfication by operators in a pre-defined set of diagnostic tests. One such test, key to prevention of flashlamp failure at full power, involves testing of all three thousand circuits at reduced energy for waveform anomalies. These tests ensure that each system component is working properly and that interfaces with other components are properly configured. The sequence of testing is ordered to provide for the dependency of one system on another. Combined subsystem or integrated testing validates the interfaces between sub-systems. The end result is confirmation that all systems are functional and ready to support operation of the laser.

Tasks associated with preparing the laser/target systems include manual setups, semi-automatic activities where computers assist operators and fully automatic tests under computer control. Figure 2 illustrates the major tasks associated with laser operation (note the logarithmic time scale). Early scheduled events are associated with time measured in minutes and seconds while events occurring during the

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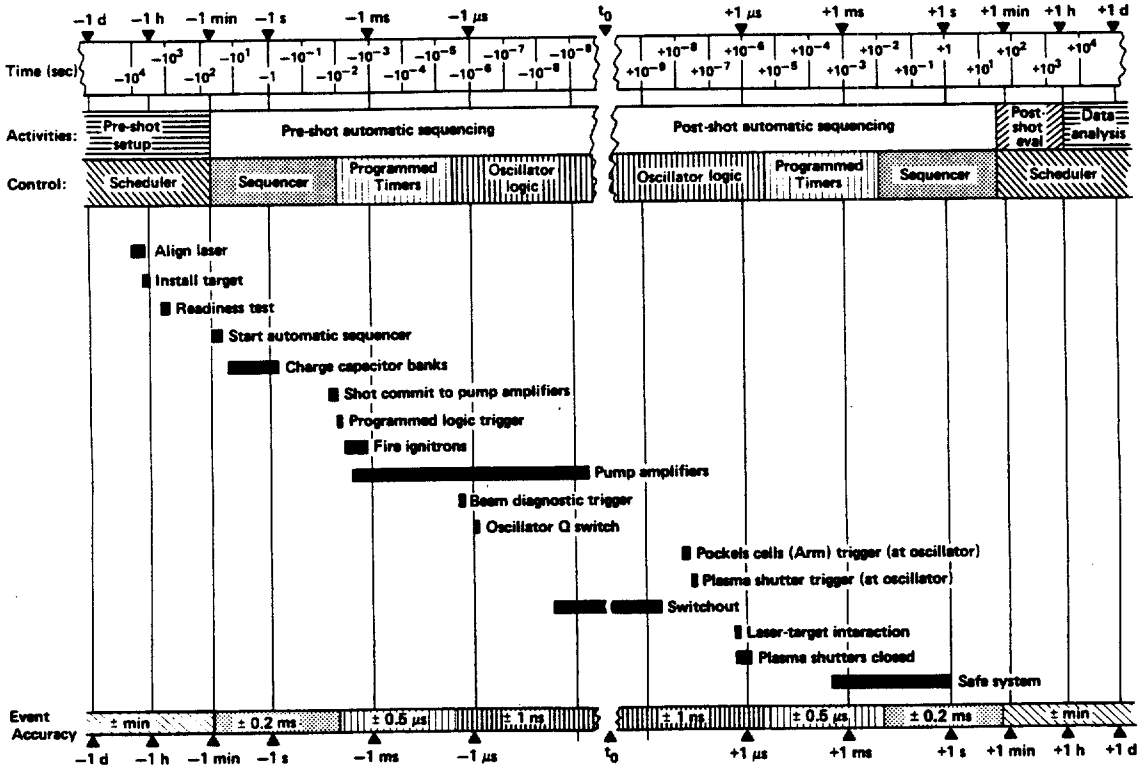


Event Timeline for Nova Operations
Drawn on a Logarithmic Time Scale

Figure 2

propogation of the laser pulse are measured in nanoseconds and picoseconds. Event timing requirements for controlling elements of the laser system span 12 orders of magnitude. This presents a control problem that is unique to laser fusion. The design of a control system to conform to this wide range of requirements is based on the use of computers and programmed logic systems. Operationally, the control system is organized into three categories where each category is assoicated with a different control technique and covers a different time span. These categories are tabulated in Figure 3 and described in the following paragraphs.

Time period*	Major tasks	Timing required	System control
— to −10 hrs	Maintenance	± minutes	Computer assisted manual operations
−10 hrs to −1 min	Laser alignment Target installation	± minutes	Scheduler checklist
−1 min to −10 ms	Charge banks	± 0.2 ms	Interrupt driven computer operations
−10 ms to −1 µs	Fire ignitrons System triggers	± 0.5 µs	Computer initialized programmed logic
−1 µs to +1 µs	Laser switchout System triggers	± 1 ns	Master oscillator electronics
+1 µs to +30 sec	Safe system	± 0.2 ms	Interrupt driven computer operations
+30 sec to +1 hr	Quick look Evaluation	± minutes	Scheduler checklist
+1 hr to —	Data analysis	± hours	Computer assisted manual operations

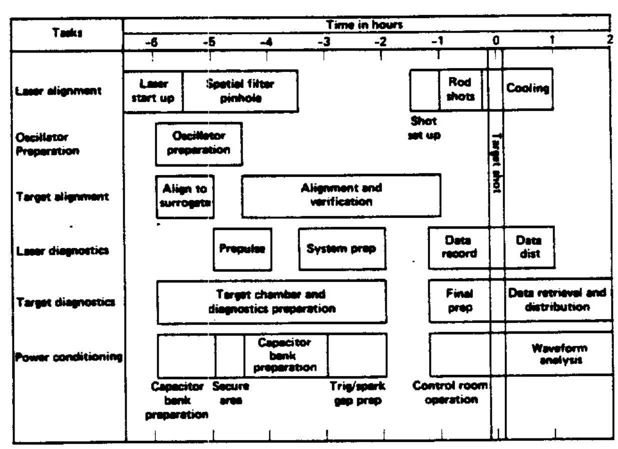
*Relative to shot time

Table of Events Associated With a Laser/Target Operation

Figure 3

Scheduler (-hours to -1 minute)

Figure 4 illustrates the major activities in preparing for a laser operation. This data reflects the Shiva laser operation and does not apply directly to the Nova laser. The difference will be a shortened time-span for Nova preparation because of increased automation of setup tasks. Each block of Figure 4 represents a set of tasks that are managed via the use of a checklist. At each step, the Shot Director verfies that the step was successfully completed before moving on to the next step. Checklists of this nature are readily automated simply by having a computer prompt the Shot Director of each decision point of the testing sequence. The computer can also



Task Timeline for the Shiva Laser

Figure 4

perform much of the test data evaluation freeing the Shot Director from routine tasks. Anomalies are rapidly brought to the attention of the Shot Director so that he can either modify the test, repeat the test or initiate diagnostic procedures. An automated checklist program of this nature is typically referred to as a scheduler. The scheduler assists the Shot Director with validation of the system while simultaneously recording data related to all tests conducted.

The scheduler oversees the preparation of the laser and target systems; when all sub-systems are determined to be ready for a shot, the scheduler initiates an automatic sequencer which executes a predefined set of commands and diagnostic routines to complete the final system preparation. The primary difference between the Scheduler and the Sequencer is that the scheduler is event driven while the sequences is time driven. The scheduler progresses from event to event where the time span to complete a given event is not fixed. The sequencer on the other hand is time ordered with each event occurring at a specific time relative to propogation of the optical pulse. The sequencer monitors the entire system for proper operation and will automatically 'hold' in the event of a system anomaly. Such anomalies include ignitron prefires, plasma shutter prefires, interlock breakage or failure of a device to respond to commands. The Shot Director can 'hold' or 'abort' the scheduler or sequencer at any time he desires.

Auto-sequencer (-1 minute to -10 ms)

At one minute prior to switchout of the laser pulse, the timing of events becomes more critical. These events are controlled by the automatic sequencer which consists of computer routes to perform control and diagnostic functions. Each sequencer event activates a routine at a predefined time measured in seconds and milliseconds preceeding laser pulse generation. Early sequencer channels are related to setup of the power conditioning system. At t-30 seconds, the sequencer initiates charging of the energy storage capacitor banks. By t-1 second, some 100 megajoules of electrical energy is stored and ready to be switched into the laser amplifiers. A key decision point occurs at switchout of the laser pulse minus 10 milliseconds. If, at this time, all systems are determined to be ready, the sequencer sends a Universal Trigger over the control system NOVABUS network. This global signal activates programmable timers throughout the laser facility. The commitment at this time is to pump the laser amplifiers but not necessarily to switchout a laser pulse. If pumping of the laser amplifiers occurs, the 100 megajoules of electrical energy is switched from the charged capacitor banks to the laser amplifier flashlamps. Removal of the resultant heat and stablization of the amplifer glass requires in excess of one hour. Thus, if the shot is aborted after t-10 msec, for any reason, an extensive delay is required before the next shot.

Programmable Timers (-10 ms to -1 μs)

During the final milliseconds, the environment that the control system must function in changes drastically. Electromagnetic noise levels increase dramatically while timing requirements are tightened to microseconds. The pumping operation requires that the electrical energy stored in capacitors be transferred to the laser amplifiers in about 1 millisecond with a peak power in excess of 100,000 megawatts. Careful design of the pulsed power system ensures that only a small fraction of this power is radiated as noise. Even so, the noise is extreme when compared with required environmental conditions for TTL/CMOS circuitry. Control system logic adjacent to the ignitron switches must not only survive but continue to operate throughout this noisy period. The most noise susceptible components are the fiber optic receivers of the NOVABUS control network. Since control signals to/from the control computer pass through these devices, control signals are subject to corruption during the high noise period. This problem is eliminated by storing commands in each device interface to be executed during the high noise interval. Device interfaces are loaded with timing information well before the pumping operation. Each device then operates independent of the control system for last 10 milliseconds prior to switchout. The timing information is loaded into device interface logic called programmable timers. All timers are activated simultaneously when the control computer sends the global Universal Trigger signal over the NOVABUS network. Programmable timers provide synchronized triggers to the devices listed in Figure 5 which includes the master oscillator. While the timers are running, the computer continues to monitor for abnormal conditions. If an 'abort' conditions arises, the computer sends a command directly to the oscillator to prevent switchout of the laser pulse. At t-1 s, a timer signal initiates Q-switching of the oscillator; the oscillator then issues a sequence of triggers to laser devices requiring submicrosecond timing.

Function	No. Timers	Fanout	End Usage
Osc synchronization	8	No	8
TV synchronization	1	Yes	6
Laser diag. sync.	6	Yes	92
Target diag. sync.	1	Yes	6
Ignitron triggers	226	No	226
	242		338

*Resolution = 1 microsecond
Jitter = ±200 nanosecond

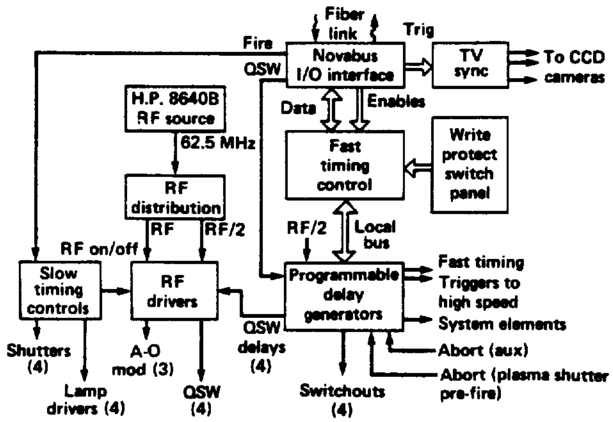
Tabulation of Programmable Timer Channels for the Nova Laser

Figure 5

Oscillator Timing (-1 μs to +1 μs)

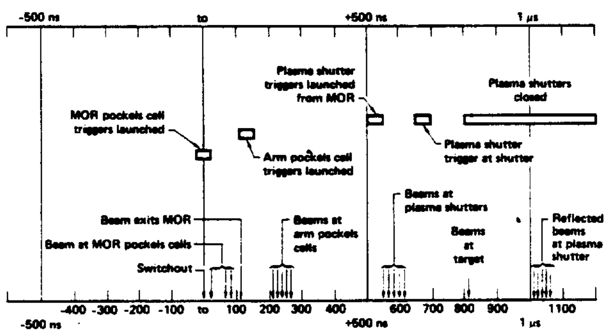
Electronics associated with the master oscillator is designed to produce timing signals with nanosecond resolution. Figure 6 is a block diagram of the oscillator timing system. The exact timing of each channel is loaded by the control computer into random access memory within the 'FAST TIMING CONTROL' block of Figure 6. Eight bit Shottky TTL counters clocked by the master r.f. oscillator output (divided by two) provide the coarse timing. By choosing either the leading or trailing edge of the symmerical 31.25 MHz clock, 16 nanosecond resolution is attained. Finally, programmable delay lines provide one nanosecond resolution. The capability to abort the switchout signal is also incorporated in the event of a plasma shutter prefire. This abort signal is by direct connection between the oscillator and plasma shutters.

Figure 7 illustrates the relationship of the timing pulses with respect to the propogation of the laser pulse. Note that certain control signals are launched after switchout of the laser pulse. Because of physical length differences, the gating signal reaches and activates its device prior to arrival of the laser pulse. Figure 8 itemizes the devices that receive fast timing triggers from the oscillator electronics.



Block Diagram of the Oscillator
Electronics Timing System

Figure 6



Event Timeline for Events Very Near
To Laser/Target Interaction

Figure 7

Function	No. Channels	Fanout	End Usage
Osc. Q-switch	4	No	4
Osc. switchout	4	No	4
Pockels cells	8	Yes	28
Plasma shutter	4	Yes	20
Beam diagnostics	20	Yes	126
Target diagnostics	2	Yes	6
	42		188

*Resolution = 1 nanoseconds
Jitter = ±100 picoseconds

Tabulation of Master Oscillator
Timing Channels

Figure 8

Post Shot (+1 μs to + hours)

Tasks associated with diagnosing how the laser/target performed begin immediately following the shot. Beam diagnostic data, target diagnostic data and power conditioning data recorded by numerous diagnostic devices are transferred to large computers for processing. This data base is used to determine how the overall system performed and to identify required adjustments prior to the next shot.

Safety Systems

Associated with the operation of a high powered laser are potential hazards to personnel. High voltages, laser beams and radiation from targets must be contained and isolated from workers. Physical barriers, electrical interlocks, visual warning displays and audible warning messages are used to protect users. Identification of potential hazards is the responsibility of each system/project engineer. This identification occurs early in the design process and is periodically reviewed as the design matures. Potential hazards are presented in the relavent Design Review and documented on a Preliminary Hazards Analysis Form including recomendations to ameliorate the hazards.

Facility or system-wide safety criteria are implemented by a centralized interlock system. This system monitors doors, oscillator shutters, beam blocks, Run/Safe monitors and Panic boxes. It generates permissives to power supplies, entry doors and oscillator shutters. Interlocks may function either mechanically or electrically to deactivate, shield or de-energize the hazard involved whenever a non-authorized entry is attempted. Electrical interlocks are implemented using redundant logic to ensure that a single point failure of the interlock logic will not produce a hazardous condition nor fail to detect a hazard. Operation of the interlock system is monitored by the computer system to detect any single failures. A single failure will not affect the laser operation but must be scheduled for repair by main tenance personnel. In addition to safety interlocks, the control room and MOR are electrically isolated from laser bay devices, target room devices and energy storage devices. This isolation is accomplished by using fiber optics to transmit and receive all control and diagnostic signals.

Interface between the human and the safety system takes many forms including physical barriers, visual displays, safety switches and audible warnings. The safety system is designed to provide the operator with visibility of potential hazards and give him methods to eliminate such hazards. Barriers are used to prevent entry of a person or a part of his body into a danger area. The type of barrier is determined by the nature of the hazard. Signs are posted to inform persons of the hazards involved and any special precautions to be observed. Doors, gates, removable panels are locked and/or interlocked. Non-interlock barriers include beam-tubes, equipment cabinets, shields and barricades. The safety system provides for automatic safing in the event of personnel entry into a hazardous area.